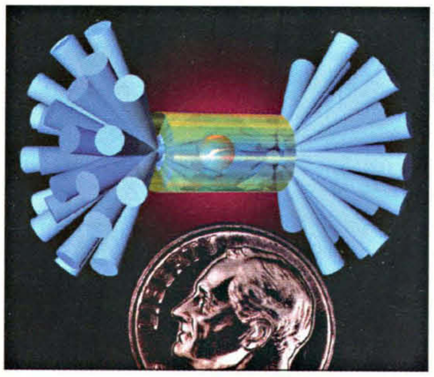
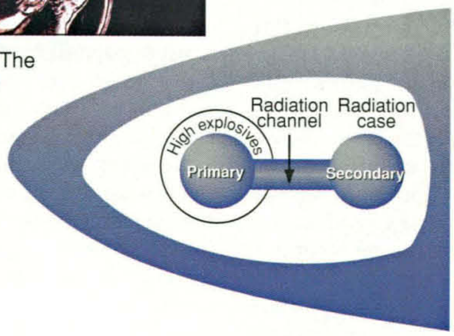
A Harsh Light Falls on NIF

This giant fusion laser is meant to simulate aspects of nuclear explosions, but critics question both its relevance to weapons and whether it can meet its technical goals

Just months before President Kennedy spoke at his 1961 inauguration of the "long twilight struggle" of the Cold War, a flicker of coherent red light emerged from a ruby crystal in a physics lab, forming the first laser. Now the twilight struggle is over. But in a historical twist, the fate of the Cold War's dangerous legacy—the aging nuclear weapons in the U.S. stockpile—is now tied to a gargantuan descendant of that first laser. With all testing halted, determining how those weapons might behave as the years take their toll could depend on this machine. It would train 192 of the world's most powerful laser beams on a speck of nuclear fuel to ignite a fusion burn—a distant relative of a nuclear explosion.

That, at least, is the argument being advanced at the U.S. Department of Energy (DOE) for constructing the $1.2 billion National Ignition Facility (NIF), a machine the size of a football stadium that, sometime after 2001, would focus 500 trillion watts of light onto a spherical fuel pellet the size of a peppercorn. Officials at DOE and at Lawrence Livermore National Laboratory in California, where the facility would be built, consider it a crucial element of so-called science-based stockpile stewardship: a program to monitor and assess the aging nuclear stockpile without actually exploding any warheads. Because NIF would let researchers study conditions close in many ways to those created in a nuclear explosion, says Bill Hogan, a NIF scientist at Livermore, "it is a key component of the entire DOE program to ensure the safety and reliability of weapons in the absence of nuclear testing."


SOURCE: LLNL



SOURCE: DOE

Telling resemblance? The x-rays generated when NIF's beams blast a minute gold capsule *(above)* could mimic radiation from a warhead's primary, which implodes the fusion-powered secondary.

But that claim has set off a Cold War–like clash among scientists, ex-bombmakers, government officials, laboratory managers, and even environmental groups. They are debating both whether the laser can live up to its technical goals and whether—even if it does—the tiny bursts of fusion it triggers will have anything to say about aging bombs, in which pure fusion is only the end result of events that begin with a conventional explosion and a burst of fission. "I do not believe the stockpile will be, in X years, in any worse shape if [NIF] did not exist," says Seymour Sack, who for 3 decades designed, developed, and managed nuclear weapons at Livermore, where he still consults. "I personally see a negligible connection."

Proponents of NIF warmly disagree. They add that the data it generates won't be viewed in isolation. Instead, results would be combined with supercomputer calculations and the results of lower energy tests on other bomb components to assess the effects of cracks, bumps, rust, degrading insulators, and decaying fuel—the often subtle changes of aging that can have notoriously large consequences for the performance of nuclear weapons. These researchers and officials also charge that many detractors from within the weapons establishment haven't fully emerged from the Cold War culture of underground tests—whose termination by Presidents Bush and Clinton led to the present stockpile stewardship program—and don't understand the possibilities offered by the power of the giant laser.

Even if NIF can open a window into the physics of aging weapons, it will only do so if it lives up to its goal of compressing and heating its fuel pellets enough for them to ignite in a self-sustaining fusion burn. Reaching ignition is essential for NIF's mission, says Victor Reis, assistant secretary for defense programs at DOE. "It isn't called a National Hope-We-Get-Ignition Facility," says Reis. "I'm not sure we could justify this system if we said [it] can't do ignition." Raising the stakes even higher is another of NIF's missions: civilian energy research. If fusion reactions in the pellet give back about 10 times the energy carried by the laser beams, say researchers, this route to fusion—called inertial confinement fusion (ICF)—is definitely worth pursuing as a commercial source of power. If the experiment does not get close to ignition, says Barrett Ripin, a longtime ICF researcher at the Naval Research Laboratory in Washington, D.C., who is now with the American Physical Society, "it would be the end of the road [for ICF energy]."

Even some supporters of the facility, however, rate its chances of ignition at only a little better than 50–50. And Ripin, who advises Livermore on ways to improve the odds, says "It is going to be very close." Other physicists put the chances at less than 10%. Adding to the doubts are an array of challenges: fabricating cryogenic fuel capsules with microscopic smoothness to ensure a symmetric implosion, producing almost an acre of precision optics that can withstand terrific light intensities, and suppressing instabilities in the ionized gas, or plasma, inside and around the fuel pellet. Researchers also disagree about the implications of a set of underground bomb tests in the 1980s, code-named Centurion/Halite, some of which checked whether a capsule could ignite under conditions roughly equivalent to those NIF is supposed to create.

The controversy is also being fueled by claims about the secondary impacts of this giant program: on the plus side, that NIF will help keep talented physicists in the weapons programs, and on the negative side, that it will siphon funds from other programs at the national laboratories. But the money for NIF is coming from the weapons budget, and as congressional scrutiny of the stockpile stewardship program intensifies (see sidebar on p. 305), doubts about NIF's relevance to weapons could hurt its chances of continued funding.

Like a bomb, only different

The weapons NIF is meant to model operate in explosive stages. First comes a "primary" that relies on conventional high explosives to trigger a fission reaction in materials such as plutonium, followed by a "secondary" that owes its awesome power to fusion reactions between the hydrogen isotopes deuterium (D) and tritium (T). To enhance the fission reaction, modern warheads "boost" the primary driver with a dash of D-T fuel, which

Stewardship Gravy Train Could Prove a Short Trip

These should be tumultuous times for the $1.2 billion National Ignition Facility (NIF)—and the $40 billion stockpile stewardship program of which it is a part. Critics of the giant fusion laser are questioning whether it can live up to its goals (see main text). And with dollars tight, Congress is wary of expensive new fusion projects. Just last week, for example, a whiff of technical and political difficulties nearly killed funding for the proposed $10 billion International Thermonuclear Experimental Reactor. It took a last-ditch effort by Energy Secretary Federico Peña to persuade a House spending panel to match the president's request for a paltry $55 million to continue design work. So why did NIF and the stockpile-stewardship program sail through the same congressional committees last week with barely a discouraging word?

The answer, in a phrase, is the Comprehensive Test Ban Treaty. President Clinton is about to ask the Senate to ratify the treaty, which would convert the current moratorium on underground testing into law. Liberals who support the treaty aren't about to jeopardize its passage by raising questions about the nation's ability to keep its nuclear arsenal in good shape without testing. And conservatives who might otherwise see the test ban as a sellout are hard pressed to defend the need for such tests when the directors of the nuclear weapons labs solemnly swear that stewardship facilities like NIF will work just as well. But this unlikely alliance of Republicans who are arms control skeptics and Democrats pressing for more radical nuclear arms reductions may not last, warn Administration officials and members of Congress.


LLNL

Groundbreaking work. A bulldozer begins preparing Livermore site for NIF.

NIF is only the most visible portion of a stewardship program at the Department of Energy (DOE) that would bestow sophisticated computer systems, experimental facilities, and a new reason for being on Lawrence Livermore, Los Alamos, and Sandia national laboratories. During Cold War days, the labs oversaw nuclear weapons design, engineering, and testing. Now, "if we want a safe and reliable deterrent [in the absence of testing], it's going to take a certain level of support," says Sig Hecker, the director of Los Alamos, who, with his two colleagues, is responsible for assuring the president each year that the nuclear stockpile is in working order.

But the program's $4-billion-a-year price tag is rising. The Senate Appropriations Committee approved $4.3 billion for 1998 to meet a string of unanticipated costs, while the House nearly matched the request. The original estimates did not include the cost of a new facility to provide tritium, a weapons component that has to be replenished, for example, and DOE has failed to reap some of the administrative savings it envisioned in 1992.

DOE had also expected to realize substantial savings by consolidating weapons-production facilities—in case new bombs ever prove necessary—at the labs. But some members of Congress are fighting the consolidation because they fear it will hurt private companies in their states, and any delay will eat up some of the planned savings. Also, Russia's continuing failure to ratify the START 2 arms control treaty means that the United States must maintain, at least for the moment, the larger and therefore more expensive START 1 stockpile. Some critics of the stewardship effort also say that DOE and lab officials are not exercising restraint in selecting an ambitious array of projects. "They're certainly going first-class; there's no doubt about it," says Spurgeon Keeny, president of the Arms Control Association.

Even the labs' staunchest ally, Senator Pete Domenici (R–NM), who chairs the panel with DOE oversight, shares the concern about rising costs. "This is a very difficult issue," he warned fellow senators last week. Domenici said he intends to press Administration officials for a clearer idea of the program's scope and costs. He is also concerned that NIF funding will eat into projects at the two labs in his home state, staffers add.

DOE headquarters' managers declined to comment on budget issues, but lab directors say they are aware of the problem. "There will be a careful counting of our pennies," says Sandia director Paul Robinson. Livermore's Bruce Tartar adds that a more detailed plan is needed. He says, "You get different [cost] estimates from different people. We ought to collectively come to a decision." Hecker agrees that "we need to revise the overall game plan," but he attributes some of the difference to uncertainty over what it will take to ensure the stockpile's readiness.

What is certain is that the program's scope and costs will be targets if and when the Senate ratifies the test ban. Neither House nor Senate is willing to approve funding for NIF beyond 1998, for example, as the White House requested. That almost guarantees a debate next year over the project. "They shouldn't buy everything in the candy shop," warns Lee Halterman, a minority House National Security Committee staffer. And if tougher budget restraints are imposed, look for intense jockeying among the labs to keep their share of the stewardship pie. **–Andrew Lawler**

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adds extra neutrons to those generated by the fissioning plutonium. X-rays from the primary are channeled—the details are of course classified—so that their pressure implodes the secondary capsule, compressing and heating it enough for D and T nuclei to overcome their mutual repulsion and fuse.

NIF exploits a tamer version of this principle of radiation-driven implosion. In pulses several billionths of a second long, its 192 ultraviolet laser beams would shine through windows at the ends of a gold case called a hohlraum, about the size of a cold capsule. Clusters of four beams illuminate 48 separate spots inside, pouring in a total of 1.8 million joules of energy, while the pressure of hydrogen and helium gas sealed inside the hohlraum helps to keep the gold walls steady as they are blasted. In the instant before it explodes, the gold hohlraum emits a uniform surge of x-rays, which crush a pellet of frozen deuterium and tritium at its center, compressing it to 20 times the density of lead and heating it to 100 million degrees Celsius.

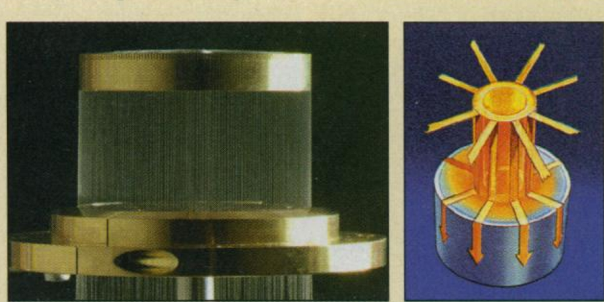
The replacement of the fission primary with a blast of laser light at much lower energy means NIF "is not a minibomb," says DOE's Reis. For this reason, even most of those who oppose the project doubt that it could lead to the development of even more advanced weapons. But Reis, who is the stockpile stewardship program's chief architect, says "we're in the ballpark" of weapons conditions in temperature, turbulence, and the jostling of radiation and plasma. Studies of those effects could validate the computer codes used to simulate nuclear explosions and model how aging and deterioration might affect them. Ignition is the ticket to that ballpark, however, says DOE's David Crandall. "We feel pretty strongly that ignition is needed for weapons physics."

Researchers at Livermore are now racing

Will NIF Put the Squeeze on Sandia's Z Pinch?

The National Ignition Facility (NIF), a massive device designed to trigger nuclear fusion by blasting a hydrogen pellet with converging laser beams (see main text), isn't the only way to bring the physics of nuclear weapons into the laboratory. Other experiments in the Department of Energy's (DOE's) stockpile stewardship program aim to complement NIF by focusing on the conventional high explosives and fissile material that trigger a hydrogen bomb. Moreover, on at least one count, NIF has an unexpected rival: a device at Sandia National Laboratory that emits powerful bursts of x-rays, comparable in some ways to those that NIF will generate to implode its target.

The Sandia experiment is the latest incarnation of a machine called a Z pinch—a simple array of wires that get vaporized by huge electrical currents, producing an ionized gas, or plasma. The currents also generate powerful magnetic fields that ring the plasma, pinching it to densities and temperatures high enough to spark a burst of x-rays. Beginning last year, a string of breakthroughs on this device has captured the attention of the weapons community. Sandia researchers discovered that by simply multiplying the number of wires in the array, they could generate far more powerful bursts of x-rays than anybody thought possible—at 200 trillion watts, or terawatts (TW), rivaling those NIF could routinely produce. "I think it's spectacular what they have done," says David Hammer, a physicist at Cornell University. "The implications are only beginning to dawn on people."



SANDIA

X-rays from Z. When current vaporizes an array of wires, magnetic fields pinch the plasma, generating a blast of x-rays.

Basic researchers like Hammer try to figure out why instabilities in the plasma don't fuzz up the collapse and limit the x-ray output. And weapons researchers are already planning to use the x-ray bursts to study the radiation damage that nuclear weapons can inflict and perhaps even—like NIF—the conditions inside an exploding weapon. But Sandia scientists and managers are looking warily over their shoulders at NIF, where construction is just beginning. "Sandia is very concerned that its funding will get gobbled up by NIF," says David Mosher, a physicist at the Naval Research Laboratory in Washington, D.C. "What they would like to do is build a larger [Z pinch]," ensuring continued funding.

In the 1950s, Z pinches were among the earliest devices for making hot, dense plasmas, or ionized gases, for fusion research. By discharging capacitor banks through, say, a neutral gas of hydrogen isotopes, researchers hoped to pinch a plasma to temperatures and densities high enough for fusion. The concept didn't pan out, but by the 1960s, Mosher realized that the Z pinch could serve a different purpose. By starting with wires made of tungsten, copper, or aluminum, he could make a plasma hot enough to put out brilliant bursts of x-rays as energetic electrons scattered off the heavy metal ions.

By the 1990s, a discharge device called Saturn, operated by the Sandia group—including Gerold Yonas, M. Keith Matzen, Donald Cook, and Thomas Sanford—had plateaued at roughly 20 TW of x-ray output. "Innovation came out of frustration," says Cook, and the team tried various ways of improving the symmetry, such as increasing the number of wires in the cylindrical array beyond the 40 or so that earlier groups had attempted.

By early last year, the peak had shot up to more than 80 TW, and a $63 million device called Z—newly upgraded to carry more current than Saturn—doubled that total last September. Using as many as 300 very narrow tungsten wires, the team recently pushed the x-ray output to 210 TW. Where the ride will end is anyone's guess. "It's in the category of a breakthrough," says Carl Ekdahl, who does nuclear-weapons studies at Los Alamos National Laboratory in New Mexico. "This opens the door to a class of experiments on x-ray flow that we did not think we would be able to do" in such a relatively inexpensive device.

The details of the physics behind these successes "have everybody baffled," says Hammer, who has set up related experiments in his own lab. But theoretical work suggests one reason the new arrays seem to generate such uniform implosions. Cook explains that the close spacing of the wires may promote fast splicing—called reconnection—of the magnetic fields that initially loop around each individual wire, quickly leading to fields that encircle the whole cylinder. Electrons could stream around those field lines and even out the fluctuations in the plasma.

Whatever the reason for the Z's burgeoning output, it now begs comparisons with the conditions likely to be generated at NIF. The x-ray energies that the Z can manage are still lower than NIF's are expected to be, although the Sandia team has lifted theirs somewhat. Soon, says Yonas, the team will also implode pellets in the Z pinch to study both weapons physics and energy applications. Cook confirms that the Sandia group would like to stay ahead in the race by building a roughly $300 million expansion of Z called X-1. But whether that money will be found is anybody's guess.

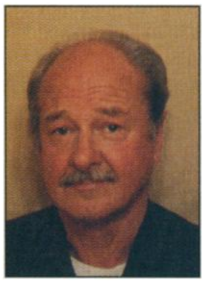
"My job is to fulfill the president's mandate" to maintain a safe, reliable nuclear stockpile without underground testing, says Victor Reis, an assistant secretary for defense programs at DOE who runs the stockpile stewardship program. "It's not to try to design a program that keeps scientists as happy as possible. We just have to look at the horses and bet on the one that looks best to us." **–J.G.**

to overcome the hurdles standing in the way of ignition, working on problems from the first glimmer of light in the laser amplifiers to the final, turbulent convulsions of the imploding capsule. Building the enormous collection of precision optics in the laser itself is a daunting challenge. NIF will require, for example, more than 3000 slabs of neodymium-doped phosphate glass, each 40 by 80 centimeters in size, to turn bursts from flash lamps into coherent laser light. Add to that a huge number of lenses, mirrors, and the fragile crystals that triple the frequency of the light generated in the amplifiers, converting it from infrared to ultraviolet. Yet another set of optical components will be needed to smooth out the inevitable beam irregularities or "hot spots"—cousins of the apparent spikes and rings in telescopic images of stars.

For the 10 smaller and less powerful beamlines of Nova, Livermore's existing laser, the optical components could be custom-made, one by one. But for NIF, the lab is working with companies to develop "continuous pour" techniques for making the glass components—so that the laser amplifiers can be churned out like office windows—along with methods of growing crystals at accelerated rates.

These components will need to be free of the kinds of flaws that could make them vulnerable to damage as the enormous pulses of light flow through them. "It's a question of whether ... the glass is going to be able to stand up to the photon flux," says David Hammer, a physicist at Cornell University who sat on the ICF Advisory Committee, a long-term review panel that gave NIF generally positive marks in its final report last year. L. Jeffrey Atherton, an associate project leader for optics technology for NIF at Livermore, agrees that "the damage issues will never be a walk in the park."

Hammer and other outside reviewers have worried that optics problems could force NIF engineers to turn down the light intensities, compromising ignition. Since he raised these concerns on the ICF committee, "there hasn't been any improvement" in finding manufacturing techniques that can meet the goals of quality and cost, says Hammer, although he still gives NIF a better-than-even chance of reaching ignition.



"As far as maintaining the stockpile is concerned, [NIF] is not necessary."

—Ray Kidder

Some of his optimism springs from progress by the Livermore researchers on another front: producing microscopically smooth shells of frozen D-T fuel. "Symmetry, symmetry, symmetry" is Hammer's mantra for a successful implosion: Capsule roughness or irregularity of more than about a micrometer would unstably grow into long "fingers," mixing cool material from the edge with the superhot core and spoiling ignition.

No matter how smooth the targets, it will be impossible to eliminate instabilities entirely. One way to minimize them, says Steven Haan, the coordinator for the design of NIF ignition targets at Livermore, is to illuminate the system with intense enough laser light to outrun the mixing. Unfortunately, raising the intensity excites "plasma waves" in the ionized gas within the hohlraum, stimulating electrons there to dance in step with the laser light. These waves can scatter the light shining into the hohlraum before it heats the gold walls, frittering away their energy. NIF engineers will have to walk a line between imploding the targets too slowly and being overtaken by mixing on the one hand, and triggering hohlraum instabilities on the other, says Haan. "It's certainly going to take experiments to determine just how high we can go," he says. "[But] we're convinced there is a point in the parameter space where we can obtain ignition."

Is the concept sound?

That conviction rests on earlier studies of the kinds of targets and energies likely to spark ignition. But there, too, some NIF critics are raising questions. These critics say their doubts are grounded in the same classified nuclear tests, the Centurion/Halite (C/H) series, that a 1990 report from the National Academy of Sciences (NAS) said had "shown qualitatively that the basic concept behind ICF is sound." The NAS's statement is usually taken as a hint that capsules were crushed to ignition when exposed to x-rays from relatively feeble nuclear explosions. Yet Charles Cranfill, who develops computer codes for weapons at Los Alamos National Laboratory in New Mexico, notes that some crucial C/H experiments failed. The details are classified, but Cranfill says the results cast doubt on the NIF program's bedrock assumptions.

Indeed, conflicting interpretations of the C/H results have nurtured a flourishing grapevine of doubt at the national laboratories about the official predictions for NIF. "To be honest, we don't even know if we'll get ignition [on NIF]," says one researcher who has detailed knowledge of the C/H results. Cranfill himself rates the chance of ignition as "very slim": 5% to 10%.

But Haan differs sharply with such views—and Haan, says E. Michael Campbell, associate director for laser programs at Livermore, "was the designer on the most successful C/H experiment. There were spectacular results." Says Haan, skating delicately around the classified details: "One could easily imagine that we may have tested a lot of different kinds of targets—not all of them cryogenic. So if some of those didn't work ... then that doesn't say anything about what the best target design will do. We learned things from C/H about what designs were the most likely to work with NIF."

"I'm not sure we could justify this system if we said [it] can't do ignition."

—Victor Reis

To Sack and some other designers, though, the technical dispute is beside the point. They say NIF data, no matter how good, will be all but useless for the stockpile. "The real problem, long-term, in the stockpile is the primaries," says another experienced weapons designer who asked not to be identified. "If anything goes wrong, the overwhelming probability is, it will be some small change in the high explosive or the fissile material, which then causes a change in boosting," leading to a large change in yield or perhaps safety problems. "And so you've got NIF to look at things which are secondary, so to speak, to the whole issue."

Campbell sees those criticisms as the expression of a bombmaking culture that cut its teeth on underground tests. Bruce Goodwin, leader of Livermore's B Division, which specializes in primaries, adds that laser experiments can do much more than many designers realize. He points to recent work by Livermore's Bruce Remington on the Nova laser, in which he used laser pulses to drive heavy metals to pressures of millions of atmospheres. Higher energy experiments on NIF, he suggests, could open a window on the behavior of metals as they are imploded in the primary. "When he did his first experiments," says Goodwin, "I was stunned that he was succeeding."

But even Ray Kidder, a retired Livermore laser physicist who headed the laser-fusion program there, agrees with Sack and his colleagues. "As far as maintaining the stockpile is concerned, [NIF] is not necessary," says Kidder. "I would use the term 'a marginal utility.' "

Fortunately for NIF, many physicists and officials have swallowed such doubts because they see other benefits to the project. Basic researchers agree, for example, that NIF would allow them to study the behavior of matter under conditions never before available in the laboratory. Kidder supports the project even though he questions its value for the weapons program. The reason: It will help keep talented physicists at Livermore. And Henry Kendall, the Massachusetts Institute of Technology physicist and self-described "peacenik" who was a founder of the Union of Concerned Scientists in 1969 and recently participated in an NAS review of NIF, speaks for many of the distinguished scientists who have lined up behind the facility.

"I'm not in a position to comment on the actual sales message that has gone out," Kendall says. "If somebody has suggested that the thing is crucial to the stewardship program, and that if we do not get NIF, everything collapses—that is certainly not right." But Kendall supports the project because he thinks it will gather some useful data, attract good scientists, and encourage the president and Congress to continue the nuclear test ban. An end to the ban, says Kendall, "would be a tragedy, because it would blight the hopes of people who have been looking toward that [goal] for decades." When the time comes for debating the Comprehensive Test Ban Treaty in Congress (see sidebar on p. 305), NIF's symbolism as a blazing end to the twilight of the Cold War could be as important as the light it sheds on fusion.

–James Glanz